Table 28. Antecedent storm data, eastern watersheds

Location of Watershed	Drainage area mi^2	Years of record	Number of floods studied	Percent in Each Case: W/out ante. rain	No break	With ante. rain	Antecedent Storm: Average dry interv. days	Median depth, percent*
Allen Creek nr Hazelwood, NC	14.4	18	10	10	10	80	3.6	26.1
WF Pigeon River above Lake Logan, NC	27.6	13	10	10	30	60	2.6	34.0
Davidson River nr Brevard, NC	40.4	47	10	30	0	70	2.9	25.7
Clear Creek nr Hendersonville, NC	42.2	10	10	0	10	90	3.1	43.3
Scott Creek above Sylva, NC	50.7	26	9	11	22	67	2.7	26.5
South Toe River at Newdale, NC	60.8	18	9	11	11	78	4.4	21.9
Cane Creek at Fletcher, NC	63.1	16	10	20	0	80	2.8	37.3
Jonathan Creek nr Cove Creek, NC	65.3	37	10	10	20	70	3.3	15.7
Mills River nr Mills River, NC	66.7	33	10	10	20	70	3.1	30.5
French Broad River at Rosman, NC	67.9	29	10	10	10	80	3.2	29.0
Hominy Creek at Candler, NC	79.8	25	10	30	0	70	2.7	27.6
Watauga River nr Sugar Grove, NC	90.8	28	10	20	10	70	2.9	43.9
North Toe River at Altapass, NC	104	24	9	0	0	100	3.0	40.2
Mud Creek at Naples, NC	109	17	10	10	0	90	3.2	45.0
Big Laurel Creek nr Stackhouse, NC	126	33	10	20	10	70	3.4	17.0
Swannanoa River at Biltmore, NC	130	33	10	20	20	60	3.5	45.3
Pigeon River at Canton, NC	133	39	10	30	10	60	2.3	39.4
Cane River nr Sioux, NC	157	33	10	10	10	80	3.5	23.7
Ivy River nr Marshall, NC	158	33	10	10	10	80	2.8	23.3
Tuckasegee River at Dillsboro, NC	347	39	10	10	30	60	2.1	19.7
Pigeon River nr Hepco, NC	350	40	10	10	20	70	3.2	8.9
French Broad River at Asheville, NC	945	72	10	10	30	60	2.6	26.6

*Percent of principal storm

Ante. = Antecedent
Interv. = Interval
W/out = Without

Table 28. Antecedent storm data, eastern watersheds

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Clear Creek nr Hendersonville, NC	42.2	10	10	0	10	90	3.1	43.3
Scott Creek above Sylva, NC	50.7	26	9	11	22	67	2.7	26.5
South Toe River at Newdale, NC	60.8	18	9	11	11	78	4.4	21.9
Cane Creek at Fletcher, NC	63.1	16	10	20	0	80	2.8	37.3
Jonathan Creek nr Cove Creek, NC	65.3	37	10	10	20	70	3.3	15.7
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French Broad River at Rosman, NC	67.9	29	10	10	10	80	3.2	29.0
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Watauga River nr Sugar Grove, NC	90.8	28	10	20	10	70	2.9	43.9
North Toe River at Altapass, NC	104	24	9	0	0	100	3.0	40.2
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*Percent of principal storm

Ante. = Antecedent
Interv. = Interval
W/out = Without

Table 29.—Summary of antecedent storm analysis

Floods analyzed	Total units studies		Percentage of floods with antecedent rain	Antecedent storm	
	Watersheds	Floods		Average dry interval, days	Median depth percent*
			Western Watersheds		
All	25	242	77	2.8	24.4
Summer	13	25	72	3.3	15.8
Winter	25	217	78	2.7	22.6
Largest flood	25	25	84	3.0	25.0
Largest two floods	25	50	84	3.0	28.5
With 7 in. or more rainfall	-	11	92	2.9	19.5
			Eastern Watersheds		
All	22	217	73	3.0	29.6
Summer	22	104	64	3.2	20.3
Winter	22	113	82	2.8	38.5
Largest flood	22	22	68	2.9	15.5
Largest two floods	22	44	73	3.3	13.9
With 7 in. or more rainfall	-	26	69	2.6	10
With 10 in. or more rainfall	-	5	100	3.3	6.6

*Percent of principal storm

This TVA study of flood-producing basin rainfall supports the inclusion of antecedent rainfall with the PMP - and TVA precipitation - level storms and also supports use of a 3-day rainless period between storms. From most of the studies reported here, the antecedent rainfall to the TVA precipitation ranges between 15 and 30 percent of the main storm. Relative to the PMP event, the TVA precipitation is a much smaller magnitude, and therefore, one would anticipate that the antecedent event to the TVA event is a greater percent of the main event than is that for the PMP event, for a similar dry interval. In order to not significantly change the probability of the combined storm event over the 3-day event, however, we have chosen an antecedent that is 15 percent of the TVA precipitation event.

7.3.6 Summary and Conclusions on Magnitude of Antecedent Storm.

Several approaches have been utilized to obtain guidance on the appropriate magnitude of a storm antecedent to the main storm. Each approach has limitations and must be carefully considered to obtain a logical conclusion. When considered in total, however, they provide a sound basis for selecting an antecedent storm to associate with the main storm in the TVA region. Following is a summary of the analysis that forms the basis for our recommendations (sect. 7.3.7.):

1. The ratio of the 9-day 100-yr to the 3-day 100-yr precipitation frequency values shows approximately 30 percent of the 3-day rain occurring in the remaining 6 days. The 10- to 3-day and 11- to 3-day 100-yr ratios show about 34 and 39 percent in the remaining 7 and 8 days, respectively. Direct application of these percents to the storm antecedent to the main storm is not justified since:

   a. Studies have shown the occurrences of the 100-yr 3-day value within the 100-yr 9-, 10-, or 11-day values were infrequent, and

   b. The 9-, 10-, and 11-day values are determined from a series of storms which did not have a 3- or 5-day dry interval between storms so that assuming all rainfall is in the first 3 days is a maximizing step.

2. Maximum 3-day rains at 250 stations in eastern Tennessee and western North Carolina with 25 yr of record were examined. In each case, the 6-day rainfall adjoining the maximum annual 3-day rain was determined. The data examined showed the decrease the percentage of the adjoining rainfall is of the maximum 3-day rain as the magnitude of the 3-day rain increases. These percentages decrease from approximately 25 percent to approximately 15 percent as the primary storm increases through the range of data available. The percentages might have been less if the 3-day dry period were a condition set in the analysis.

   A similar study was completed using the maximum 8-day rainfall surrounding or adjoining the annual maximum 3-day event. In this case also, there was a decrease in the percentage the adjacent rain is of the maximum 3-day rain as the magnitude of the 3-day rain increases. For the smaller

storms the percentage is nearly 60 percent, while for storms greater than 6 in. it is only 34 percent.

In each portion of the study, the relationships were extrapolated to indicate an appropriate percentage at the magnitude of the 3-day main storm precipitation. These percentages indicated from 10 to 15 percent for the 6-day and from 25 to 30 percent for the 8-day adjacent rains, respectively.

3. Maximum 9-day rains greater than 4.5 in. at Asheville, Memphis, Birmingham and Louisville during the period 1912-61 were examined. Again, there is a definite decrease in the percent the adjacent rain is of the maximum 3-day rain as the magnitude of the maximum 3-day rain increases. This decreases from about 54 percent for rains between 3 to 4 in. to about 24 percent for rains greater than 6 in. There were 67 large (>6 in.) rainfall cases considered in this portion of the study. Maximum 10- and 11-day rains for these stations were also evaluated. For the 10-day rains the percentages decrease from 68 percent (for rains between 3 and 4 in.) to 25 percent (for rains greater than 6 in.) and for the 11-day rains from 88 to 30 percent. There were 58 and 43 cases of 10- and 11-day rains, respectively.

Envelopment curves of 9-, 10-, and 11-day ratios based on extreme storms at Memphis, TN; Asheville, NC; Birmingham, AL, and Louisville, KY indicate decreasing values as the magnitude of the 3-day rain increases. The 9-day to 3-day ratio would be less than 120 percent and the 10- and 11-day to 3-day ratio would be between 120 and 125 percent.

4. Since the 25 to 50 yr of data available at most stations is an inadequate sample when considering storms approaching PMP magnitude and the rareness of the event that is necessary in these designs, statistical procedures were used to generate 40 samples of 100 yr of record. From each sample, all 3-day rains greater than 7 in. and the associated 6 days before or after were selected. A near enveloping trend line again shows the same decrease that the adjoining rain is of the maximum 3-day rain as the 3-day rain increases in magnitude. An enveloping line modeled after the trend line shows a percentage less than 30 percent at the magnitude of the PMP.

5. Since the station rainfall statistics are most representative of the lower end of the size spectrum under consideration, large major storms were examined. Three pairs of major storms were considered first. The data show that antecedent rainfall, as the percent of the major storm, decreases as the magnitude of major storm increases. Extrapolation beyond observed amounts to larger values indicates a lower percent for antecedent rainfall as would be expected from the meteorological constraints that the more intense the storm, the more unlikely it is that a strong inflow of moisture will develop in a short time.

6. Rainfalls antecedent to 23 tropical and 11 extratropical storms for 2,000-mi^2 areas were considered. First, rainfall adjacent to the storm at the location of the storm was examined for a 6-day adjoining rainfall period. Then the largest rainfall within 300 mi was considered for all 34 cases for a 6-day adjoining period. In each case, there is a decrease in the percentage the adjacent rain is of the maximum 3-day rain as the magnitude of the 3-day rain increases. Enveloping curves for all data for the case of the adjacent storm occurring at the location of the major storm indicate the adjacent rainfall at the magnitude of the PMP would be about 24 percent of the 3-day storm for the 3-day dry interval.

For application to the PMP sequence, a maximizing step is to consider that the rains occurred either before or after the primary storm anywhere within a 300-mi radius of the primary storm. For the 3-day dry interval, the data indicate a ratio of less than 30 percent for the antecedent rain.

7.3.7 Recommendations

From the various approaches for guidance on the magnitude of rain prior to the PMP, this report recommends that 30 percent of the PMP be used for the antecedent storm when a 3-day dry interval is specified. When the 3-day dry interval is increased to 5 days, the bulk of data indicate some slight increase from similar ratios for the 3-day interval. This report suggests 39 percent of the PMP for a 5-day dry interval.

From the analysis of the data discussed in section 7.3.5 and the independent TVA study (Newton and Lee 1969), antecedent rainfall of 15 percent of the main storm is considered reasonable for TVA storm events separated by a 3-day dry interval.

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REFERENCES

Bonner, W.O., Esbensen, S., and Greenberg, R, 1968: Kinematics of the Low Level Jet. Journal of Applied Meteorology, Vol. 7, No. 3, pp. 339-347.

Changnon, S.A. Jr., 1968: Climatology of Hourly Occurrences of Selected Atmospheric Phenomena in Illinois.

Dodd, A.V., 1965: Dew Point Distribution in the Contiguous United States. Monthly Weather Review, Vol. 93, No. 2, pp. 113-122.

Environmental Data Service, 1896-1976: Climate and Crop Service, 1896-1910; Monthly Weather Review, 1910-13; Climatological Data by Sections, 1914-76, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Asheville, NC.

Environmental Data Service, 1968: National Climatic Atlas of the United States, ESSA, U.S. Department of Commerce, Washington, DC, 80 pp.

Fenn, D.D., 1985: Probable Maximum Precipitation Estimates for the Drainage Above Dewey Dam, Johns Creek, Kentucky. NOAA Technical Memorandum NWS HYDRO 41, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 33 pp.

Frederick, R.H., 1973: Time Distribution of Precipitation in 3- to 10-Day Storms-Arkansas-Canadian River Basins. NOAA Technical Memorandum NWS HYDRO 15, National Weather Service, Silver Spring, MD, 45 pp.

Frederick, R.H., Myers, V.A. and Auciello, E.P., 1977: Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States. NOAA Technical Memorandum NWS HYDRO 35, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 36 pp.

Fritsch, J.M. and Maddox, R.A., 1981: Convectively Driven Mesoscale Weather Systems Aloft. Part I: Observations. Journal of Applied Meteorology, Vol. 20, No. 1, pp 9-19.

Hansen, E.M., Schreiner, L.C. and Miller, J.F., 1982: Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian. Hydrometeorological Report No. 52, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, DC, 168 pp.

Hershfield, D.M., 1961: Rainfall Frequency Atlas of the United States for Durations 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. Technical Paper No. 40, Weather Bureau, U.S. Department of Commerce, Washington, DC, 115 pp.

Ho, F.P. and Riedel, J.T., 1980: Seasonal Variation of 10-Square Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. Hydrometeorological Report No. 53, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 59 pp.

Huff, F.A., 1967: Mesoscale Structure of Severe Rainstorms. Proceedings of the Fifth Conference on Severe Local Storms, American Meteorological Society, Boston, MA, pp. 211-215.

Huff, F.A. and Changnon, S.A. Jr., 1961: Severe Storms in Illinois 1958-59. Report of Investigation No. 42, Illinois Water Survey, Urbana, IL, 70 pp.

Jennings, A.H., 1952: Maximum 24-Hour Precipitation in the United States. Technical Paper No. 16, Weather Bureau, U.S. Department of Commerce, Washington, DC, 284 pp.

Kleinsasser, T.W., 1958: Meteorology of Intense Storm Rainfall of November 18, 1957 Near Spring City, Tennessee. TVA Report No. 16, Appendix A, Knoxville, TN, 4 pp.

Maddox, R.A., 1981: Satellite Depiction of the Life Cycle of a Mesoscale Convective Complex. Monthly Weather Review, Vol. 109, No. 7, pp 1583-1586.

Means, L.L., 1952: On Thunderstorm Forecasting in the Central United States. Monthly Weather Review, Vol. 80, No. 10, pp. 165-189.

Miller, J.F., 1964: Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States. Technical Paper No. 49, Weather Bureau, U.S. Department of Commerce, Washington, DC, 29 pp.

Miller, J.F. and Frederick, R.H., 1972: Time Distribution of Precipitation in 4- to 10-Day Storms - Ohio River Basin. NOAA Technical Memorandum NWS HYDRO 13, National Weather Service, National Oceanic and Atmospheric Administration, Silver Spring, MD, 41 pp.

Miller, J.F., Hansen, E. M., Fenn, D.D., Schreiner, L.C. and Jensen, D.T., 1984a: Probable Maximum Precipitation Estimates - United States Between the Continental Divide and 103rd Meridian. Hydrometeorological Report No. 55, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 245 pp.

Miller, J.F., Hansen, E.M. and Fenn, D.D., 1984b: Probable Maximum Precipitation for the Upper Deerfield River Drainage Massachusetts/Vermont. NOAA Technical Memorandum NWS HYDRO 39, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 36 pp.

Myers, V.A., 1959: Meteorology of Hypothetical Flood Sequences in the Mississippi River Basin. Hydrometeorological Report No. 35, U.S. Weather Bureau, U.S. Department of Commerce, Washington, DC, 46 pp.

Myers, V.A., 1967: Meteorological Estimation of Extreme Precipitation for Spillway Design Floods. NOAA Technical Memorandum HYDRO-5, Weather Bureau, Environmental Science Services Administration, U.S. Department of Commerce, Washington, DC, 14 pp.

Neumann, C.J., Cry, G.W., Caso, E.L. and Jarvinen, B.R., 1978: Tropical Cyclones of the North Atlantic, 1871-1977. National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, NC, 170 pp.

Newton, D.W. and Lee, R.G., 1969: Storms Antecedent to Major Floods. Proceedings of the 50th Annual Meeting of the American Geophysical Union.

O'Connor, J.F., 1965: The Weather and Circulation of October 1964. Monthly Weather Review, Vol. 93, No. 1, pp. 59-66.

Peck, E.L., Monro, J.C. and Snellson, M.L., 1977: Hydrometeorological Data Base for the United States. Proceedings of the Second Conference on Hydrometeorology, American Meteorological Society, Boston, MA, pp. 75-78.

Riedel, J.T., Appleby, J.F. and Schloemer, R.W., 1956: Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas of 10 to 1,000 Square Miles and Durations of 6, 12, 24, and 48 Hours. Hydrometeorological Report No. 33, U.S. Weather Bureau, U.S. Department of Commerce, Washington, D.C., 58 pp.

Sangster, W.E., 1967: Diurnal Surface Geostrostrophic Wind Variations Over the Great Plains. Proceedings From the Fifth Conference on Severe Storms, American Meteorological Society, Boston, MA, pp. 146-153.

Schoener, R.W. and Molansky, S., 1956: Rainfall Associated With Hurricanes. National Hurricane Research Project, Report No. 33, Weather Bureau, U.S. Department of Commerce, Washington, DC, 305 pp.

Schreiner, L. C. and Riedel, J. T., 1978: Probable Maximum Precipitation Estimates, United States East of 105th Meridian. Hydrometeorological Report No. 51, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, DC, 87 pp.

Schwarz, F.K., 1961: Meteorology of Flood-Producing Storms in the Ohio River Basin. Hydrometeorological Report No. 38, U.S. Weather Bureau, U.S. Department of Commerce, Washington, DC, 67 pp.

Schwarz, F.K., 1963: Probable Maximum Precipitation in the Hawaiian Islands. Hydrometeorological Report No. 39, Weather Bureau, U.S. Department of Commerce, Washington, DC, 98 pp.

Schwarz, F.K., 1965: Probable Maximum and TVA Precipitation Over the Tennessee River Basin Above Chattanooga. Hydrometeorological Report No. 41, U.S. Weather Bureau, U.S. Department of Commerce, Washington, DC, 148 pp.

Schwarz, F.K. and Helfert, N.F., 1969: Probable Maximum and TVA Precipitation for Tennessee River Basins up to 3,000 Square Miles in Area and Durations to 72 Hours. Hydrometeorological Report No. 45, U.S. Weather Bureau, Environmental Science Services Administration, U.S. Department of Commerce, Silver Spring, MD, 166 pp.

Schwarz, F.K., 1973: Addendum to Hydrometeorological Report No. 45, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD, 22 pp.

Showalter, A.K., 1953: A Stability Index for Thunderstorm Forecasting. Bulletin of the American Meteorological Society, Vol. 34, No. 6, Boston, MA, pp. 250-252.

Tennessee Valley Authority, 1924-1982: Intense Storms Over Small Areas. On-going publication, Knoxville, TN.

Tennessee Valley Authority, 1961: Floods and Flood Control. Technical Report No. 26, Tennessee Valley Authority, Knoxville, TN, 45 pp.

Tennessee Valley Authority, 1965: Floods of September-October 1964 in the Upper French Broad Little Tennessee and Hiwassee River Basin. Report No. 0-6491, Tennessee Valley Authority, Knoxville, TN, 185 pp.

Tennessee Valley Authority, 1969: Mean Precipitation in the Tennessee River Basin. Supplement to Precipitation in Tennessee River Basin, Annual 1969.

U.S. Army Corps of Engineers, 1945- : Storm Rainfall in the United States, Washington, DC.

U.S. Weather Bureau, 1947: Generalized Estimates of Maximum Possible Precipitation Over the United States East of the 105th Meridian. Hydrometeorological Report No. 23, U.S. Department of Commerce, Washington, DC, 62 pp.

U.S. Weather Bureau, 1956: Maximum Station Precipitation for 1, 2, 3, 6, 12, and 24 hours Tennessee, Technical Paper No. 15, Weather Bureau, U.S. Department of Commerce, Washington, DC, 82 pp.

U.S. Weather Bureau, 1957: Rainfall Intensity Frequency Regime. Part I - The Ohio Valley. Technical Paper No. 29, Weather Bureau, U.S. Department of Commerce, Washington, DC, 44 pp.

U.S. Weather Bureau, 1966: Probable Maximum Precipitation Estimates - Northwest States. (Including revision of 1981.) Hydrometeorological Report No. 43, Environmental Science Services Administration, U.S. Department of Commerce, Washington, DC, 228 pp.

Woodley, W.L., 1967: An Examination of an Instance of Heavy, Non-Frontal Wintertime Convective Rain in the Southeastern United States. Proceedings of the Fifth Conference on Severe Local Storms, American Meteorological Society, Boston, MA, pp. 198-208.

World Meteorological Organization, 1973: Manual for Estimation of Probable Maximum Precipitation. Operational Hydrology Report No. 1, WMO No. 332, Geneva, Switzerland, 190 pp.